FAA/EUROCONTROL COOPERATIVE R&D

ACTION PLAN 16: Common Trajectory Prediction Capability

TP Requirements Engineering Methodology paper

EXECUTIVE SUMMARY

Unless broad categories of improvements are made, most air service providers view the future of civil air transport as increasing in demand faster than capacity, making it increasingly difficult to maintain yet alone improve the current levels of safety and efficiency. Decision Support Tools (DSTs) provide support to flight data processing, metering, or conflict prediction functions. The common thread to all these tools is the trajectory predictor (TP) that is responsible for predicting the anticipated future path of the aircraft. As a result, the performance of the TP is critical to the success of these DST functions.

To help meet this future challenge, an international team of researchers and practitioners has been formed. This team aims to minimise duplication of effort in the many organisations involved in tool and TP development, thereby reducing costs, reducing time to deployment, and enhancing the quality of the validation and performance improvement process.

The goal of this paper is to facilitate a common methodology for eliciting and understanding the variation in TP requirements across the community for emerging and future automation in Air Traffic Management (ATM) systems, i.e., ground based DSTs and the TP functionality embedded in aircraft systems, related to ATM applications. The work should lead to the identification of the set of existing and "proposed" TP requirements that are or could be commonly shared across multiple systems. The scope of the TP requirements survey is limited to applications that are currently in operation or emerging applications that are at relatively high level of technical maturity.

The paper indicates that the requirements survey needs to consist of a top-down path that will elicit the TP requirements from the various client applications, and a bottom-up path, that will capture TP performance capabilities from different existing TP distributions. These initiatives need to be followed by a validation and verification effort before realistic system specifications can be produced.

It is recommended that the community participates in the survey of TP requirements. The community is requested to (1) provide feedback on this methodology paper, (2) share specific TP requirements and performance information.

Table of Contents

1 Objective

The objective of this White Paper is to facilitate the compilation, comparative analysis, and sharing of Air Traffic Management (ATM) community requirements for Trajectory Prediction (TP). The goal is to understand the variation in TP requirements across the community for emerging and future ATC automation, ground based Decision Support Tools (DST) and the TP functionality embedded in aircraft systems, that are related to ATM applications. The work should lead to the identification of the set of already validated and "proposed" TP requirements that are or could be commonly shared across multiple systems. Better understanding of commonly shared and unique TP requirements will facilitate the definition of a more consistent and complete set of TP specifications across the ATM industry.

2 Scope

The scope of the TP requirements survey is limited to TP client applications that are currently in operation or emerging applications that are at a relatively high level of technical maturity. This will allow the team to get a handle on the topic and set the stage for a broader scope. Future enhancements of this survey will need to expand the scope to include far-term concepts such as the support of "autonomous aircraft" or "automated airspace" concepts. Therefore the target TP functionality will be limited to two categories of applications, namely,

A. Applications that are currently mature, e.g. Flight Planning, Air Traffic Flow Management, Flight Data Processing Systems, Medium Term Conflict Detection and Arrival Management tools, etc. and,
B. Applications that are the subject of "applied research" activities, e.g. air-ground co-ordination, DSTs that aim to lower the complexity level of the future traffic situations (multi-sector planning tools) , DSTs that facilitate a "greener ATM", e.g. through the application of Area Navigation procedures and advanced Arrivals Management tools, etc.

The main difference between these two categories is the target look-ahead time that needs to be achieved within given accuracy bounds. Typically, applications of the first category focus either on global flight planning covering the flight from gate-to-gate but with relatively low accuracy requirements, or target to improve sector productivity thereby requiring high accuracy but with a limited look-ahead time. An "Open Loop" trajectory prediction strategy based on estimated flight intent, aircraft performance and meteorological conditions is typically the approach used today.

Applications of the second category require look-ahead times of sometimes up to one hour or longer and target to provide high prediction accuracy at traffic convergence points. Such applications require active control loops to ensure that the uncertainty is maintained within a practical range. Typical examples are:

- Airborne systems that maintain a constraint defined by the ground system (e.g. the Required Time of Arrival (RTA) at a defined way point) and that are uplinked to the aircraft, or,
- Active ATC advisories generated by the ground system that are communicated to the aircraft though Radio Telephony or datalink. (e.g. advanced Arrivals Management (AMAN), Conflict Resolution assistant (CORA), etc.).

Note that it may well be that hybrid approaches, i.e. approaches that integrate air and ground control loops, may be the most promising in the short to medium term future before advanced autonomous-aircraft/automated-airspace concepts achieve the operational maturity.

3 Rationale

Identification of a common set of requirements is not a purely academic exercise, nor is the first step in building an all-purpose TP. The identification of common requirements (or common requirement characteristics) enables the following:

1. Knowledge of common requirements allows the development and acquisition of common data for validation and verification of TP. This data can be shared amongst developers and users to ensure efficiency in testing and validation.
2. Identification of critical issues and requirements in general and according to application allows the focusing of research and development expenditures in areas that will provide improvements to the community at large.
3. Knowledge of shared requirements will facilitate the sharing of validated TP components to reduce the cost of future TP development.
4. Knowledge of prior TP requirements helps future developers ensure completeness of future requirements.
5. A common requirements engineering process that considers ground and airborne applications will ensure ultimately the necessary consistency of the predicted trajectories in both application domains.

It is our intention that this paper will encourage you to share your needs for and know how on TP requirements including solutions that you apply or intend to apply for requirements validation and verification. Sharing this information will facilitate the definition of a more consistent, complete and validated set of specifications across the ATM industry. As a result this common understanding of the TP requirement issues will lead to less duplication in system R&D, a faster track towards implementation, and to better interoperability between system components.

4 Background

The development of common methods and resources for the validation and improvement of TP capabilities is the key motive for initiating Action Plan 16 of the Eurocontrol/FAA R&D Committee [Ref. 1] and the CARE/TP Action [Ref. 2]. The work plans consist of multiple activities/work packages that address key issues of common interest across our community. The activities are coordinated through a Core Team that consists of TP experts from NASA, FAA, CENA, CAASD and Eurocontrol.

This White Paper contributes to the processes of TP-requirements survey that will help define key performance indicators of common interest for TP processes. In the same context two more White Papers have been produced by the Core Team namely, on common TP terminology [Ref. 3] and on validation data methodology [Ref. 4].

5 Requirements Engineering for TP

The primary measure of success of a Trajectory Predictor is the degree to which it meets the purpose for which it was intended. The purpose may vary greatly from client to client as there are many ATM-automation clients that require the services of a Trajectory Predictor. Broadly speaking, *Requirements Engineering for Trajectory Prediction* is the process of discovering that purpose, by identifying stakeholders and their needs, and documenting these in a form that is amenable to analysis, communication, and subsequent implementation [Ref. 5]. Requirements engineering is generally the responsibility of the client application.

The first step in the client's requirements engineering process is typically to *capture* the requirements. Although this term suggests that requirements can simply be collected by asking the right questions of the domain experts, this often appears not to be the case. The information collected in the requirements capture process needs to be *interpreted, analysed, modelled and validated* before it can be *verified* that a sufficiently complete set of requirements is available from which system specifications can be defined.

For many client applications, good, clear and consistent TP requirements are not well defined. Because Trajectory Predictors are already in common use in ATM applications, the process of Requirements Capture does not have to start from scratch. We can first identify and summarize the de facto requirements of legacy applications, and then capture the changes in TP requirements that are needed to deliver the enhanced ATM system performance, e.g. to facilitate the introduction of new or better performing ATC tools.

6 Context

One of the current trends in ATM system evolution is to further improve the ATM system performance by implementing new automation and procedures that reduce the complexity level of the future traffic situation. This requires a move from a largely tactical approach towards a concept based on enhanced, "trajectory based" planning capabilities. The further improvement of the interoperability between airborne and ground based automation functions will be an essential catalyst. This "trajectory-based" ATM approach may require improvements in TP performance over the present situation to achieve a better correlation between the actual trajectories flown and the ones computed by the TP. In addition, it will probably be needed to increase the look-ahead time for which usable trajectory data can be predicted. These "high level" requirements need to be translated in practical TP requirements that can be modeled and validated.

In recent years a significant effort has been placed on the improvement of sector productivity. This led to the development of, among other things, conflict probing tools. The performance of these tools in operational systems did not always match the initial expectations due to the relative high levels of uncertainty associated with the predicted trajectories. Moreover, it is challenging, to say the least, to find documentation in the literature of both the initial requirements, prior to development, and the final results validating the TP performance to support these tools. It is even more challenging to be able to cross-compare requirements and results across comparable client tools/automation in operation with various Air Traffic Service Providers (ATSPs). This makes it difficult, if not impossible, to learn and leverage from each other's triumphs and lessons. The need for more formal requirements engineering may be even greater in the future.

It can be expected that the requirements for trajectory prediction will vary among client applications, e.g. TP requirements in support of oceanic applications, will be different from those for Terminal Maneuvering Area (TMA) applications. It is the objective of Action Plan 16 to collect these requirements with the objective to provide guidance for the development of common Trajectory Predictor components that will avoid the need for the development of entirely different, unique, dedicated TPs. A noble goal is to learn and leverage from what is shared in common.

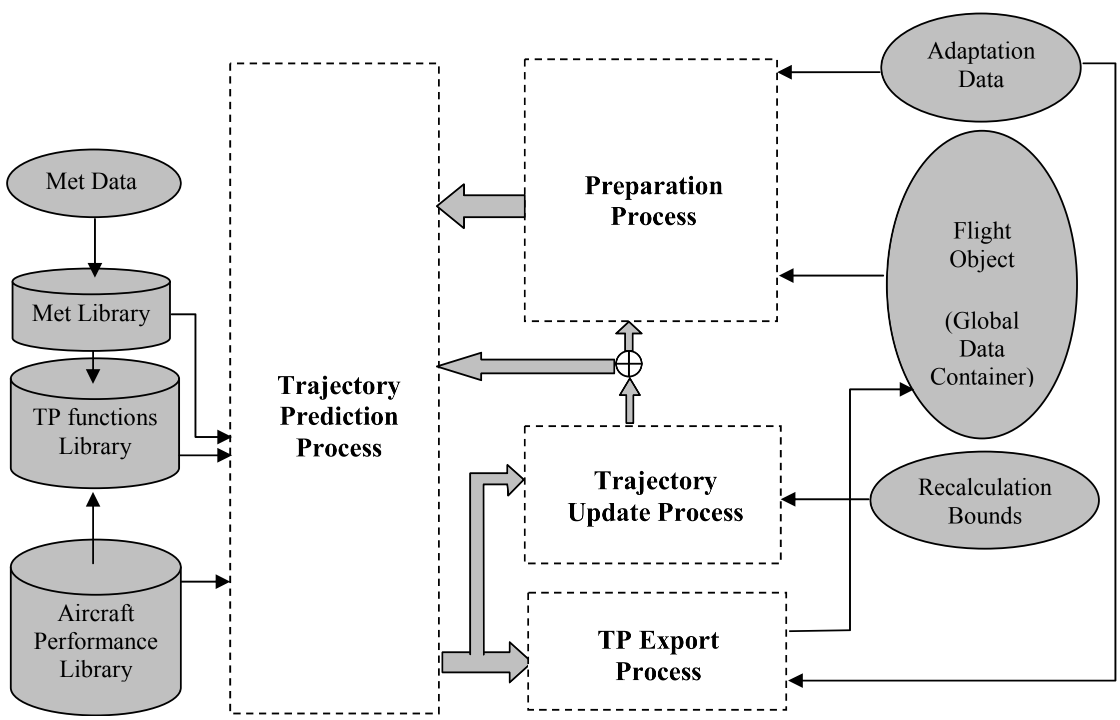

Fig 1 Trajectory Predictor related processes

Individual Trajectory Predictors may vary in their implementation, particularly depending on the integration with the TP client and the system architecture in which they are embedded. The White Paper on Common Terminology [Ref. 3] illustrates a common model whereby the Trajectory Predictor can be decomposed into four distinct, but closely related processes: the Preparation process, the Trajectory Prediction process, the

Trajectory Export process and the Trajectory Update process (See Fig. 1 in Ref. 3)[1]. This generalized model for Trajectory Predictors lends itself to finding the maximum level of commonality.

The Requirements Engineering process for TP focuses at defining, validating and verifying the requirements for the individual processes that comprise the TP. The provision of these services through Trajectory Predictors that consist of common, duly validated components will ensure a consistent performance level, ease interoperability issues and reduced overall development and maintenance costs.

7 TP performance characteristics

The *accuracy* of a TP can be measured by performing post flight comparisons between predicted and observed trajectories. These data constitute the basis for estimating the *uncertainty* that limits the accuracy with which trajectories can be predicted. The latter data are paramount for designers of ATM Decision Support Tools (DSTs) as these have a direct impact on the performance and the usability of these tools. The frequency with which TP services are requested by the clients depends largely on how the tool is using the predicted trajectories internally. In Decision Support Tools where the demand for Trajectory Prediction updates is controlled through a Conformance Monitoring process, the frequency of requesting new predictions may be low, whereas, if a DST is based on a continuous update approach (e.g., for "closed loop" control), the demand for TP services may be very high. This has an impact on the minimum acceptable *response time* from the Trajectory Predictor. In practice, it will not be feasible to maximize all TP performance characteristics simultaneously, therefore it is likely that trade-offs will be required between operationally achievable accuracy, uncertainty and response time. The optimal balance of TP performance characteristics will depend on the specific nature and needs of the client application.

The above characteristics are often referred to as "*non-functional*": they summarize the global performance characteristics of the TP. In contrast "*functional*" characteristics describe the level of detail with which *intent* can be described, which parameters will be processed by the Trajectory Predictor and how. Airborne intent describes how the aircraft will be controlled by the pilot or the Flight Management System[2]. Ground based intent describes the tactical guidance and/or constraints that the controller defines. There is a close relationship between the functional and non-functional performance characteristics. The correlation between predicted and observed trajectories will be greater, if the detail with which intent information is processed is greater and/or if more available input data sources are used or the quality of these is enhanced. In this context we can consider the use of down linked aircraft data, intent inferencing, etc. This improves the accuracy of

[1] At the macro-system level the TP processes can then be considered as the *methods* of the *TP object*, whereas the Flight Object is the *data container* that is shared with the other ATM system objects, thus ensuring the consistency needed.

[2] Often, from the airborne perspective, it is understood that *intent* describes the notional path and/or constraints the aircraft will follow in the future. In this view, intent would be part of the *output* of the TP process. However, from the perspective of the Trajectory Prediction process, *intent* information needs to be part of the *input* data. This difference in views is a serious potential source of confusion.

the predicted trajectories and thus reduces the uncertainty, but it may also increase the response time due to more complex internal data processing. Following a top-down approach, the definition of the non-functional requirements will probably drive the definition of the functional requirements. Taking a bottom-up view, we can see that the target *system architecture* for a particular TP client will have an impact on the achievable overall system performance, in particular in relation to the implemented communication backbone between TP and client application(s).

8 Survey of TP requirements

To collect a complete and consistent set of functional and non-functional TP-performance requirements it is necessary to investigate the different aspects that affect the requirements. Different TP requirements may be elicited depending on the perspective of the client application. There are the *functional* point of view, the impact of different *traffic complexities* in which the applications are used, *flight efficiency* considerations, different *availability and quality of flight data*, the target *ATM system architecture* in which the TP will be implemented, etc. Moreover, the ATM system as a whole evolves. Therefore one also needs to consider the anticipated *evolution* in client requirements.

9 Validation of TP requirements

ATM systems are built and implemented by the ATM industry on the basis of specifications provided by Air Navigation Service Providers (ANSPs). The specification process requires the translation of operational requirements into traceable system specifications. This process is often painful and frustrating.

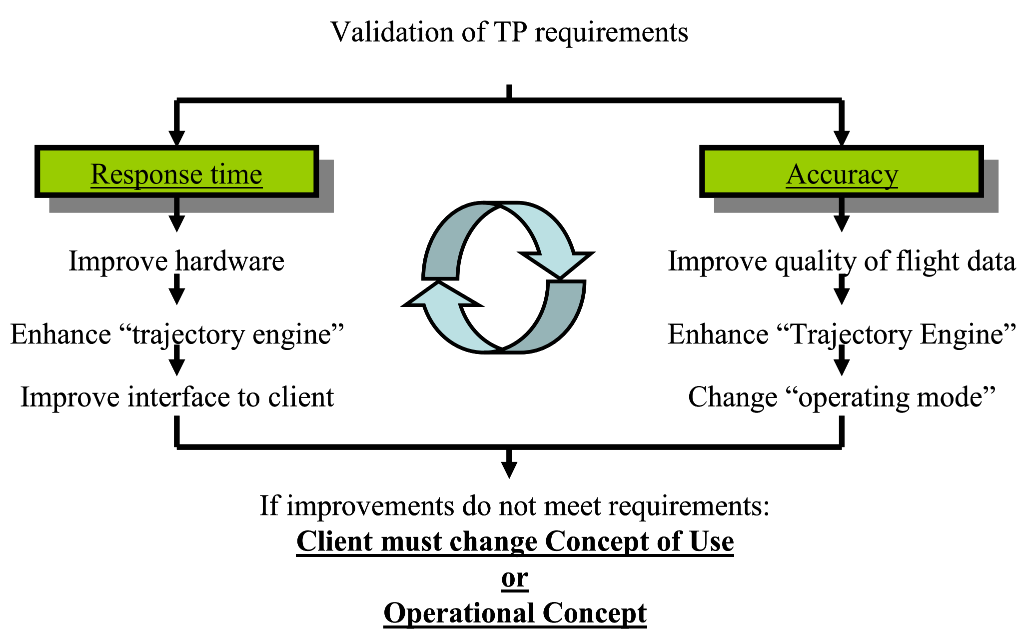

Fig. 2 Trade-off process to force compromises in TP requirements

During the system development process requirements are often adapted or deleted to prevent cost or schedule overruns. Therefore, after collecting the requirements, a strong need exists for a validation process. This will confirms that the requirements captured provide an accurate account of the needs and wants of the individual TP clients and that they are technically feasible.

If, in a given operational and technical context, the TP performance does not meet the requirements, the difference needs to be resolved in one way or another. If needed, accuracy can be improved (uncertainty reduced) by enhancing the requirements on input data, increasing the fidelity of the algorithms within the Trajectory Engine and/or more detailed intent specification in the Flight Script, etc. If needed, response time can be improved by increasing the TP integration step, simplifying the data models used, reducing the amount of input data, reducing the fidelity of the algorithms in the Trajectory Engine, the level of detail of the intent information in the Flight Script and/or using higher-performance hardware and middleware.

If this process does not converge to an acceptable set of TP requirements, it may be necessary to adapt the ATM operational concept to obtain a better match between the TP performance that is achievable and the updated TP client requirements. This is an interactive process that may require several iterations. To this effect the availability of a suitable requirements validation tool set is essential.

10 Verification of TP requirements

After the set of functional and non-functional performance requirements have been surveyed and validated, it is essential to verify that this set is sufficiently complete to constitute the basis for system specification.

11 A practical way forward

11.1 Leverage of existing material

TP requirements engineering does not start from scratch. Much work has already been accomplished. The challenge is to leverage and build on past work and to fill in what is missing. Every ATM system fielded today is likely to have a known set of specifications based on requirements. Unfortunately these system requirements and specifications often have a "Company Confidential" status. In References [6] and [7] we present examples of existing, publicly available TP requirements originating from Eurocontrol and the FAA, respectively. From the information presented it is clear that a consistent, complete and comprehensive set of TP requirements is not yet available. A significant effort is still needed to achieve this.

11.2 Schedule

For practical reasons we will need to prioritize the phases of the requirements engineering process. The survey of TP requirements from existing ATM applications comprises a first step. Functional and non-functional requirements can be collected, processed and an overview can be produced. Eliciting requirements from more advanced applications that are still on the drawing board may require the iterative approach discussed earlier. Therefore this will be a longer term process. The requirements validation and verification processes need to follow suit in due course.

11.3 Strategies for Requirements survey

We consider two complementary streams of activities for TP requirements capture:

1. The *top-down approach* whereby TP performance requirements are defined by the TP clients, e.g., Flight Planning tools, ATFM applications, DSTs and Flight Management Systems. This path will produce the list of *minimum* requirements that a Trajectory Predictor needs to fulfil in the given operational context before receiving the label “fit for the purpose”. A possible method to elicit explicit requirements could be through structured questionnaires. These questionnaires need to ensure that the requirements are expressed in a consistent way so as to be cross comparable (i.e., we can identify the aspects that are shared in common and differentiate those aspects that are unique).
   TP client applications may express their specific needs that will allow them to support the use of (P)RNAV procedures, Continuous Descent Approach (CDA) procedures, various distributed air-ground applications, Conflict Detection & Resolution tools (like CORA), etc. Analysis of the *explicit requirements* will uncover the *implicit requirements*, e.g. those related to the details of the intent information that needs to be encoded in the Flight Script and the characteristics of the aircraft performance model.
2. In contrast, the *bottom-up approach* estimates what performance a TP can deliver on the basis of a given set of input data of which the quality and availability is known and the system architecture in which the TP software will be embedded. This path builds on the results obtained from Action Item 4, “Comprehensive Sensitivity Analysis of TP Factors”, of the AP16 work plan [Ref. 1] and the performance of advanced TP prototypes. This bottom-up path determines the *maximum* performance bounds requirements that a TP can deliver in a given operational context from a basic physics and system architectural point of view. Some feed-back to the DST designers on the consequences of the TP performance limitations have already been delivered earlier [Ref. 8, 9, 10].

11.4 Requirements validation

In a later step, we need to confirm that a given set of TP requirements elicited through the top-down process indeed can be met by a practical TP approach. Moreover, ATC concept and DST designers face the challenge of interoperability among the proposed DSTs in a target operational concept. The need for these DSTs to have access to a common, consistent view of the future traffic situation is paramount, but specific requirements, e.g., on accuracy and response time, may vary. To that effect a Requirements Validation Tool Set is needed. This tool set should support the integration of models and/or prototypes of the DSTs together with the target TP distribution(s), the flight data container (see Fig. 1) and data feeds to update its internal data from simulated and/or recorded operational flight data. In practice, a requirements validation tool set will probably closely interact with the validation process. Consequently, a common approach for tool development could well be envisaged.

11.5 Requirements verification

After the set of TP requirements is validated, it needs to be verified that the set is consistent and complete. With a positive result the product of the Requirements Engineering process is ready to support the system-specification task.

12 Summary

Individual TP client applications may have different requirements, functional and non-functional. There is no reason to expect that these requirements will significantly diverge, but there is also no guarantee that the total set of requirements will be coherent or complete unless/until we systematically analyze the requirements. The technical feasibility to meet requirements needs to be confirmed, considering the availability and quality of input data, available resources for software development, target implementation schedule, budget and data processing capabilities.

We have identified four distinct phases for the TP requirements engineering process:

(1) Initiate a comprehensive survey of *TP requirements*. In a first step we will concentrate on the needs of known TP client applications. The requirements will be formulated such that they can lead to the development of a Common Trajectory Prediction Capability. This step will be performed as a top-down process. In a later phase the requirements of future ATM client applications can be considered.

(2) Initiate a comprehensive survey of *performance capabilities* of existing TPs and TP prototypes. This is a bottom-up process.

(3) Provide a *requirements validation tool set* to ensure that a given set of TP requirements can be met by the performance available from practical Trajectory Predictors in the target system architecture, and, that this combination is sufficiently performing to meet the TP client requirements.

(4) *Verify* that the TP requirements are sufficiently complete and consistent so that technical and operational specifications for operational systems can be developed.

13 Recommendations to the Community

A framework for, in particular, the eliciting TP requirements has been proposed to promote the improvement of trajectory predictor performance. We encourage your participation in the following ways:

1. **Provide feedback on this White Paper, preferably in writing.** All your comments will be reviewed thoroughly by the team and incorporated in a subsequent version of the paper. Please use the attached comment form (file name: "ActionPlan16Comments01.doc") and mail to: tim-tp@cena.fr by October 25, 2004.
2. **Share the TP requirements of your current and proposed TP applications.**
3. **Share the performance characteristics of your TP distributions.**
4. **Participate in the Technical Interchange Meeting[3] (TIM) organized to exchange community feedback on TP requirements survey and establish a list of continuing participants.** The TIM will promote open exchanges and discussions of functional and non-functional TP requirements, allow the community to present internal successes of overlapping activities, and better explain the team's expectations of the effort. We encourage your participation not only by attending but also by presenting a briefing of your local experiences on TP requirements. Please send a message with your intentions on attending and your proposition to tim-tp@cena.fr by October 1, 2004.

A community survey of TP requirements and related validation and verification efforts requires community support to be successful. More importantly, it will serve the TP development community and the service providers and in turn the public. It promotes the improvement of TP accuracy and capabilities required for the implementation of DSTs and other ATM-related automation, and improve the interoperability of air and ground automation. This will ultimately contribute to the improvement of ATM system safety and efficiency.

14 Acronyms

AP16	FAA-Eurocontrol R&D Committee – Action Plan 16
AMAN	Arrival Manager
ATC	Air Traffic Control
ATFM	Air Traffic Flow Management
ATM	Air Traffic Management
ATSP/ANSP	Air Traffic/Navigation Service Provider
CARE	Co-operative Actions of R&D in Eurocontrol
CDA	Continuous Descent Approach
CENA	Centre d'Études de la Navigation Aérienne
CORA	Conflict Resolution Assistant

[3] TIM is scheduled for late November 2004. The logistical details will be provided in a separate document.

DST	Decision Support Tool
FAA	Federal Aviation Authority
FDPS	Flight Data Processing System
FMS	Flight Management System
HIPS	Highly Interactive Problem Solver
Met	Meteorological data
MTCD	Medium Term Conflict detection tool
NASA	National Aeronautics and Space Administration
PHARE	Programme of Harmonized Research in Eurocontrol
RTA	Required Time of Arrival
STCA	Short Term Conflict Alert tool
TMA	Terminal Manoeuvring Area
TP	Trajectory Predictor

15 References

[1] FAA-Eurocontrol R&D Committee, Action Plan 16, Common Trajectory Prediction Capability, http://www.eurocontrol.int/faa-euro/start.html

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[3] CTPC Team, FAA-Eurocontrol R&D Committee AP16; March 2003, White Paper: "Common Trajectory Prediction related terminology", White Paper; TIM-TP/02, Toulouse November 04; http://www.eurocontrol.int/faa-euro/start.html

[4] CTPC Team, FAA-Eurocontrol R&D Committee AP16; March 2003, White Paper: "Validation Data Methodology", White Paper; TIM-TP/02, Toulouse November 04; http://www.eurocontrol.int/faa-euro/start.html

[5] B. Nuseibeh, S. Easterbrook; "Requirements engineering: a roadmap"; http://www.doc.ic.ac.uk/~ban/pubs/sotar.re.pdf

[6] "Operational requirements for Trajectory Prediction for EATCHIP Phase III" http://www.eurocontrol.int/odt/documents/library.html

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[10] R. Irvine; "Target miss distance to achieve a required probability of conflict", ATM 2003 R&D Conference, Paper 75, Budapest, June 2003, http://atm2003.eurocontrol.fr